THERMAL PROTECTION FOR LAMP BALLASTS

FIELD OF THE INVENTION

[0001] This invention relates to thermal protection for lamp ballasts. Specifically, this invention relates to a ballast having active thermal management and protection circuitry that allows the ballast to safely operate when a ballast over-temperature condition has been detected, allowing the ballast to safely continue to provide power to the lamp.

BACKGROUND OF THE INVENTION

[0002] Lamp ballasts are devices that convert standard line voltage and frequency to a voltage and frequency suitable for a specific lamp type. Usually, ballasts are one component of a lighting fixture that receives one or more fluorescent lamps. The lighting fixture may have more than one ballast.

[0003] Ballasts are generally designed to operate within a specified operating temperature. The maximum operating temperature of the ballast can be exceeded as the result of a number of factors, including improper matching of the ballast to the lamp(s), improper heat sinking, and inadequate ventilation of the lighting fixture. If an over-temperature condition is not remedied, then the ballast and/or lamp(s) may be damaged or destroyed.

[0004] Some prior art ballasts have circuitry that shuts down the ballast upon detecting an over-temperature condition. This is typically done by means of a thermal cut-out switch that senses the ballast temperature. When the switch detects an over-temperature condition, it shuts down the ballast by removing its supply voltage. If a normal ballast temperature is subsequently achieved, the switch may restore the supply voltage to the ballast. The result is lamp flickering and/or a prolonged loss of lighting. The flickering and loss of lighting can be annoying. In addition, the cause may not be apparent and might be mistaken for malfunctions in other electrical systems, such as the lighting control switches, circuit breakers, or even the wiring.

SUMMARY OF THE INVENTION

[0005] A lamp ballast has temperature sensing circuitry and control circuitry responsive to the temperature sensor that limits the output current provided by the ballast when an over-temperature condition has been detected. The control circuitry actively adjusts the output current

as long as the over-temperature condition is detected so as to attempt to restore an acceptable operating temperature while continuing to operate the ballast (i.e., without shutting down the ballast). The output current is maintained at a reduced level until the sensed temperature returns to the acceptable temperature.

[0006] Various methods for adjusting the output current are disclosed. In one embodiment, the output current is linearly adjusted during an over-temperature condition. In another embodiment, the output current is adjusted in a step function during an over-temperature condition. In yet other embodiments, both linear and step function adjustments to output current are employed in differing combinations. In principle, the linear function may be replaced with any continuous decreasing function including linear and non-linear functions. Gradual, linear adjustment of the output current tends to provide a relatively imperceptible change in lighting intensity to a casual observer, whereas a stepwise adjustment may be used to create an obvious change so as to alert persons that a problem has been encountered and/or corrected.

[0007] The invention has particular application to (but is not limited to) dimming ballasts of the type that are responsive to a dimming control to dim fluorescent lamps connected to the ballast. Typically, adjustment of the dimming control alters the output current delivered by the ballast. This is carried out by altering the duty cycle, frequency or pulse width of switching signals delivered to a one or more switching transistors in the output circuit of the ballast. These switching transistors may also be referred to as output switches. An output switch is a switch, such as a transistor, whose duty cycle and/or switching frequency is varied to control the output current of the ballast. A tank in the ballast's output circuit receives the output of the switches to provide a generally sinusoidal (AC) output voltage and current to the lamp(s). The duty cycle, frequency or pulse width is controlled by a control circuit that is responsive to the output of a phase to DC converter that receives a phase controlled AC dimming signal provided by the dimming control. The output of the phase to DC converter is a DC signal having a magnitude that varies in accordance with a duty cycle value of the dimming signal. Usually, a pair of voltage clamps (high and low end clamps) is disposed in the phase to DC converter for the purpose of establishing high end and low end intensity levels. The low end clamp sets the minimum output current level of the ballast, while the high end clamp sets its maximum output current level.

[0008] According to one embodiment of the invention, a ballast temperature sensor is coupled to a foldback protection circuit that dynamically adjusts the high end clamping voltage in accordance with the sensed ballast temperature when the sensed ballast temperature exceeds a threshold. The amount by which the high end clamping voltage is adjusted depends upon the

difference between the sensed ballast temperature and the threshold. According to another embodiment, the high and low end clamps need not be employed to implement the invention. Instead, the foldback protection circuit may communicate with a multiplier, that in turn communicates with the control circuit. In this embodiment, the control circuit is responsive to the output of the multiplier to adjust the duty cycle, pulse width or frequency of the switching signal.

[0009] The invention may also be employed in connection with a non-dimming ballast in accordance with the foregoing. Particularly, a ballast temperature sensor and foldback protection are provided as above described, and the foldback protection circuit communicates with the control circuit to alter the duty cycle, pulse width or frequency of the one or more switching signals when the ballast temperature exceeds the threshold.

[0010] In each of the embodiments, a temperature cutoff switch may also be employed to remove the supply voltage to shut down the ballast completely (as in the prior art) if the ballast temperature exceeds a maximum temperature threshold.

[0011] Other features of the invention will be evident from the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a functional block diagram of a prior art non-dimming ballast.

[0013] Figure 2 is a functional block diagram of a prior art dimming ballast.

[0014] Figure 3 is a functional block diagram of one embodiment of the present invention as employed in connection with a dimming ballast.

[0015] Figure 4a graphically illustrates the phase controlled output of a typical dimming control.

[0016] Figure 4b graphically illustrates the output of a typical phase to DC converter.

[0017] Figure 4c graphically illustrates the effect of a high and low end clamp circuit on the output of a typical phase to DC converter.

[0018] Figure 5a graphically illustrates operation of an embodiment of the present invention to linearly adjust the ballast output current when the ballast temperature is greater than threshold T1.

[0019] Figure 5b graphically illustrates operation of an embodiment of the present invention to reduce the ballast output current in a step function to a level L1 when the ballast temperature is greater than threshold T2, and to increase the output current in a step function to 100% when the ballast temperature decreases to a normal temperature T3.

[0020] Figure 5c graphically illustrates operation of an embodiment of the present invention to adjust the ballast output current linearly between temperature thresholds T4 and T5, to reduce the ballast output current in a step function from level L2 to level L3 if temperature threshold T5 is reached or exceeded, and to increase the output current in a step function to level L4 when the ballast temperature decreases to threshold T6.

[0021] Figure 5d graphically illustrates operation of an embodiment of the present invention to adjust the ballast output current in various steps for various thresholds, and to further adjust ballast output current linearly between levels L6 and L7 if the stepwise reductions in output current are not sufficient to restore the ballast temperature to normal.

[0022] Figure 6 illustrates one circuit level implementation for the embodiment of Figure 3 that exhibits the output current characteristics of Figure 5c.

[0023] Figure 7 is a functional block diagram of another embodiment of the present invention for use in connection with a dimming ballast.

[0024] Figure 8 is an output current versus temperature response for the embodiment of Figure 7.

[0025] Figure 9 is a functional block diagram of an embodiment of the present invention that may be employed with a non-dimming ballast.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] Turning now to the drawings, wherein like numerals represent like elements there is shown in Figures 1 and 2 functional block diagrams of typical prior art non-dimming and dimming ballasts, respectively. Referring to Figure 1, a typical non-dimming ballast includes a front end AC to DC converter 102 that converts applied line voltage 100a, b, typically 120 volts AC, 60 Hz, to a higher voltage, typically 400 to 500 volts DC. Capacitor 104 stabilizes the high voltage output on 103a, b of AC to DC converter 102. The high voltage across capacitor 104 is presented to a back end DC to AC converter 106, which typically produces a 100 to 400 Volt AC output at 45 KHz to 80 KHz at terminals 107a, b to drive the load 108, typically one or more florescent lamps. Typically, the ballast includes a thermal cut-out switch 110. Upon detecting an over-temperature condition, the thermal cutout switch 110 removes the supply voltage at 100a to shut down the ballast. The supply voltage is restored if the switch detects that the ballast returns to a normal or acceptable temperature.

[0027] The above description is applicable to Figure 2, except that Figure 2 shows additional details of the back end DC to AC converter 106, and includes circuitry 218, 220 and 222 that permits the ballast to respond to a dimming signal 217 from a dimming control 216. The

dimming control 216 may be any phase controlled dimming device and may be wall mountable. An example of a commercially available dimming ballast of the type of Figure 2 is model number FDB-T554-120-2, available from Lutron Electronics, Co., Inc., Coopersburg, PA, the assignee of the present invention. As is known, the dimming signal is a phase controlled AC dimming signal, of the type shown in Figure 4a, such that the duty cycle of the dimming signal and hence the RMS voltage of the dimming signal varies with adjustment of the dimming actuator. Dimming signal 217 drives a phase to DC converter 218 that converts the phase controlled dimming signal 217 to a DC voltage signal 219 having a magnitude that varies in accordance with a duty cycle value of the dimming signal , as graphically shown in Figure 4b. It will be seen that the signal 219 generally linearly tracks the dimming signal 217. However, clamping circuit 220 modifies this generally linear relationship as described hereinbelow.

[0028] The signal 219 stimulates ballast drive circuit 222 to generate at least one switching control signal 223a, b. Note that the switching control signals 223a, b shown in Figure 2 are typical of those in the art that drive output switches in an inverter function (DC to AC) in the back-end converter 106. An output switch is a switch whose duty cycle and/or switching frequency is varied to control the output current of the ballast. The switching control signals control the opening and closing of output switches 210, 211 coupled to a tank circuit 212, 213. Although Figure 2 depicts a pair of switching control signals, 223a, b, an equivalent function that uses only one switching signal may be used. A current sense device 228 provides an output (load) current feedback signal 226 to the ballast drive circuit 222. The duty cycle, pulse width or frequency of the switching control signals is varied in accordance with the level of the signal 219 (subject to clamping by the circuit 220), and the feedback signal 226, to determine the output voltage and current delivered by the ballast.

[0029] High and low end clamp circuit 220 in the phase to DC converter limits the output 219 of the phase to DC converter. The effect of the high and low end clamp circuit 220 on the phase to DC converter is graphically shown in the Figure 4c. It will be seen that the high and low clamp circuit 220 clamps the upper and lower ends of the otherwise linear signal 219 at levels 400 and 401, respectively. Thus, the high and low end clamp circuitry 220 establishes minimum and maximum dimming levels.

[0030] A temperature cutoff switch 110 (Figure 1) is also usually employed. All that has been described thus far is prior art.

[0031] Figure 3 is a block diagram of a dimming ballast employing the present invention. In particular, the dimming ballast of Figure 2 is modified to include a ballast temperature sensing circuit 300 that provides a ballast temperature signal 305 to a foldback protection circuit 310. As

described below, the foldback protection circuit 310 provides an appropriate adjustment signal 315 to the high and low end clamp circuit 220' to adjust the high cutoff level 400. Functionally, clamp circuit 220' is similar to clamp circuit 220 of Figure 2, however, the clamp circuit 220' is further responsive to adjustment signal 315, which dynamically adjusts the high end clamp voltage (i.e. level 400).

[0032] The ballast temperature sensing circuit 300 may comprise one or more thermistors with a defined resistance to temperature coefficient characteristic, or another type of temperature sensing thermostat device or circuit. Foldback protection circuit 310 generates an adjustment signal 315 in response to comparison of temperature signal 305 to a threshold. The foldback protection circuit may provide either a linear output (using a linear response generator) or a step function output (using a step response generator), or a combination of both, if the comparison determines that an over-temperature condition exists. In principle, the exemplary linear function shown in Figure 3 may be replaced with any continuous function including linear and non-linear functions. For the purpose of simplicity and clarity, the linear continuous function example will be used. But, it can be appreciated that other continuous functions may equivalently be used. Regardless of the exact function used, the high end clamp level 400 is reduced from its normal operating level when the foldback protection circuit 310 indicates that an over-temperature condition exists. Reducing the high end clamp level 400 adjusts the drive signal 219' to the ballast drive circuit 222 so as to alter the duty cycle, pulse width or frequency of the switching control signals 223a, b and hence reduce the output current provided by the ballast to load 108. Reducing output current should, under normal circumstances, reduce the ballast temperature. Any decrease in ballast temperature is reflected in signal 315, and the high end clamp level 400 is increased and/or restored to normal, accordingly.

[0033] Figures 5a – 5d graphically illustrate various examples of adjusting the output current during an over-temperature condition. These examples are not exhaustive and other functions or combinations of functions may be employed.

[0034] In the example of Figure 5a, output current is adjusted linearly when the ballast temperature exceeds threshold T1. If the ballast temperature exceeds T1, the foldback protection circuit 310 provides a limiting input to the high end clamp portion of the clamp circuit 220'so as to linearly reduce the high end clamp level 400, such that the output current may be reduced linearly from 100% to a preselected minimum. The temperature T1 may be preset by selecting the appropriate thresholds in the foldback protection circuit 310 as described in greater detail below. During the over-temperature condition, the output current can be dynamically adjusted in the linear region 510 until the ballast temperature stabilizes and is permitted to be restored to

normal. Since fluorescent lamps are often operated in the saturation region of the lamp (where an incremental change in lamp current may not produce a corresponding change in light intensity), the linear adjustment of the output current may be such that the resulting change in intensity is relatively imperceptible to a casual observer. For example, a 40% reduction in output current (when the lamp is saturated) may produce only a 10% reduction in perceived intensity.

[0035] The embodiment of the invention of Figure 3 limits the output current of the load to the linear region 510 even if the output current is less than the maximum (100%) value. For example, referring to Figure 5a, the dimming control signal 217 may be set to operate the lamp load 108 at, for example, 80% of the maximum load current. If the temperature rises to above a temperature value T1, a linear limiting response is not activated until the temperature reaches a value of T1*. At that value, linear current limiting may occur which will limit the output current to the linear region 510. This allows the maximum (100%) linear limiting profile to be utilized even if the original setting of the lamp was less than 100% load current. As the current limiting action of the invention allows the temperature to fall, the lamp load current will once again return to the originally set 80% level as long as the dimmer control signal 217 is unchanged.

[0036] In the example of Figure 5b, output current may be reduced in a step function when the ballast temperature exceeds threshold T2. If the ballast temperature exceeds T2, then the foldback protection circuit 310 provides a limiting input to the high end portion of the clamp 220' so as to step down the high end clamp level 400; this results in an immediate step down in supplied output current from 100% to level L1. Once the ballast temperature returns to an acceptable operating temperature T3, the foldback protection circuit 310 allows the output current to immediately return to 100%, again as a step function. Notice that recovery temperature T3 is lower than T2. Thus, the foldback protection circuit 310 exhibits hysteresis. The use of hysteresis helps to prevent oscillation about T2 when the ballast is recovering from a higher temperature. The abrupt changes in output current may result in obvious changes in light intensity so as to alert persons that a problem has been encountered and/or corrected.

[0037] In the example of Figure 5c, both linear and step function adjustments in output current are employed. For ballast temperatures between T4 and T5, there is linear adjustment of the output current between 100% and level L2. However, if the ballast temperature exceeds T5, then there is an immediate step down in supplied output current from level L2 to level L3. If the ballast temperature returns to an acceptable operating temperature T6, the foldback protection circuit 310 allows the output current to return to level L4, again as a step function, and the output current is again dynamically adjusted in a linear manner. Notice that recovery temperature T6 is lower than T5. Thus, the foldback protection circuit 310 exhibits hysteresis, again preventing

oscillation about T5. The linear adjustment of the output current between 100% and L2 may be such that the resulting change in lamp intensity is relatively imperceptible to a casual observer, whereas the abrupt changes in output current between L2 and L3 may be such that they result in obvious changes in light intensity so as to alert persons that a problem has been encountered and/or corrected.

[0038] In the example of Figure 5d, a series of step functions is employed to adjust the output current between temperatures T7 and T8. Particularly, there is a step-wise decrease in output current from 100% to level L5 at T7 and another step-wise decrease in output current from level L5 to level L6 at T8. Upon a temperature decrease and recovery, there is a step-wise increase in output current from level L6 to level L5 at T11, and another step-wise increase in output current from level L5 to 100% at T12 (each step function thus employing hysteresis to prevent oscillation about T7 and T8). Between ballast temperatures of T9 and T10, however, linear adjustment of the output current, between levels L6 and L7, is employed. Once again, step and linear response generators (described below) in the foldback protection circuitry 310 of Figure 3 allow the setting of thresholds for the various temperature settings. One or more of the step-wise adjustments in output current may result in obvious changes in light intensity, whereas the linear adjustment may be relatively imperceptible.

[0039] In each of the examples, a thermal cutout switch may be employed, as illustrated at 110 in Figure 1, to remove the supply voltage and shut down the ballast if a substantial over-temperature condition is detected.

[0040] Figure 6 illustrates one circuit level implementation of selected portions of the Figure 3 embodiment. The foldback protection circuit 310 includes a linear response generator 610 and a step response generator 620. The adjustment signal 315 drives the output stage 660 of the phase to DC converter 218' via the high end clamp 630 of the clamp circuit 220'. A low end clamp 640 is also shown.

[0041] Temperature sensing circuit 300 may be an integrated circuit device that exhibits an increasing voltage output with increasing temperature. The temperature sensing circuit 300 feeds the linear response generator 610 and the step response generator 620. The step response generator 620 is in parallel with the linear response generator 610 and both act in a temperature dependent manner to produce the adjustment signal 315.

[0042] The temperature threshold of the linear response generator 610 is set by voltage divider R3, R4, and the temperature threshold of the step response generator 620 is set by voltage divider R1, R2. The hysteresis characteristic of the step response generator 620 is achieved by means of feedback, as is well known in the art.

[0043] The threshold of low end clamp 640 is set via a voltage divider labeled simply VDIV1. The phase controlled dimming signal 217 is provided to one input of a comparator 650. The other input of comparator 650 receives a voltage from a voltage divider labeled VDIV2. The output stage 660 of the phase to DC converter 218' provides the control signal 219'.

[0044] Those skilled in the art will appreciate that the temperature thresholds of the linear and step response generators 610, 620 may be set such that the foldback protection circuit 310 exhibits either a linear function followed by a step function (See Figure 5c), or the reverse. Sequential step functions may be achieved by utilizing two step response generators 620 (See steps L5 and L6 of Figure 5d). Likewise, sequential linear responses may be achieved by replacing the step response generator 620 with another linear response generator 610. If only a linear function (Figure 5a) or only a step function (Figure 5b) is desired, only the appropriate response generator is employed. The foldback protection circuit 310 may be designed to produce more than two types of functions, e.g., with the addition of another parallel stage. For example the function of Figure 5d may be obtained with the introduction of another step response generator 620 to the foldback protection circuit, and by setting the proper temperature thresholds.

[0045] Figure 7 is a block diagram of a dimming ballast according to another embodiment of the invention. Again, the dimming ballast of Figure 2 is modified to include a ballast temperature sensing circuit 300 that provides a ballast temperature signal 305 to a foldback protection circuit 310. The foldback protection circuit 310' produces, as before, an adjustment signal 315' to modify the response of the DC to AC back end 106 in an over-temperature condition. Nominally, the phase controlled dimming signal 217 from the dimming control 216, and the output of the high and low end clamps 220, act to produce the control signal 219 that is used, for example, in the dimming ballast of Figure 2. However, in the configuration of Figure 7, the control signal 219 and the adjustment signal 315' are combined via multiplier 700. The resulting product signal 701 is used to drive the ballast drive circuit 222' in conjunction with feedback signal 226. It should be noted that ballast drive circuit 222' performs the same function as the ballast drive circuit 222 of Figure 3 except that ballast drive circuit 222' may have a differently scaled input as described hereinbelow.

[0046] As before, in normal operation, dimming control 216 acts to deliver a phase controlled dimming signal 217 to the phase to DC converter 218. The phase to DC converter 218 provides an input 219 to the multiplier 700. The other multiplier input is the adjustment signal 315'.

[0047] Under normal temperature conditions, the multiplier 700 is influenced only by the signal 219 because the adjustment signal 315' is scaled to represent a multiplier of 1.0.

Functionally, adjustment signal 315' is similar to 315 of Figure 3 except for the effect of scaling. Under over-temperature conditions, the foldback protection circuit 310' scales the adjustment signal 315' to represent a multiplier of less than 1.0. The product of the multiplication of the signal 219 and the adjustment signal 315' will therefore be less than 1.0 and will thus scale back the drive signal 701, thus decreasing the output current to load 108.

[0048] Figure 8 illustrates the response of output current versus temperature for the embodiment of Figure 7. As in the response shown in Figure 5a, at 100% of load current, the current limiting function may be linearly decreasing beyond a temperature T1. However, in contrast to Figure 5a, the response of the embodiment of Figure 7 at lower initial current settings is more immediate. In the multiplier embodiment of Figure 7, current limiting begins once the threshold temperature of T1 is reached. For example, the operating current of the lamp 108 may be set to be at a level lower than maximum, say at 80%, via dimmer control signal 217 which results in an input signal 219 to multiplier 700. Assuming that the temperature rises to a level of T1, the multiplier input signal 315' would immediately begin to decrease to a level below 1.0 thus producing a reduced output for the drive signal 701. Therefore, the 100% current limiting response profile 810 is different from the 80% current limiting response profile 820 beyond threshold temperature T1.

[0049] It can be appreciated by one of skill in the art that the multiplier 700 may be implemented as either an analog or a digital multiplier. Accordingly, the drive signals for the multiplier input would be correspondingly analog or digital in nature to accommodate the type of multiplier 700 utilized.

[0050] Figure 9 illustrates application of the invention to a non-dimming ballast, e.g., of the type of Figure 2, which does not employ high end and low end clamp circuitry or a phase to DC converter. As before, there is provided a ballast temperature sensing circuit 300 that provides a ballast temperature signal 305 to a foldback protection circuit 310''. The foldback protection circuit 310' provides an adjustment signal 315'' to ballast drive circuit 222. Instead of adjusting the level of a high end clamp, the adjustment signal 315'' is provided directly to ballast drive circuit 222. Otherwise the foregoing description of the function and operation of Figure 3, and the examples of Figures 5a – 5d, are applicable.

[0051] The circuitry described herein for implementing the invention is preferably packaged with, or encapsulated within, the ballast itself, although such circuitry could be separately packaged from, or remote from, the ballast.

[0052] Figure 10 illustrates a light fixture 1000 having a ballast 1010 that employs the present invention. The circuitry for implementing the invention can be integral with or packaged within, or external to, the ballast.

[0053] It will be apparent to those skilled in the art that various modifications and variations may be made in the apparatus and method of the present invention without departing from the spirit or scope of the invention. For example, although a linearly decreasing function is disclosed as one possible embodiment for implementation of current limiting, other continuously decreasing functions, even non-linear decreasing functions, may be used as a current limiting mechanism without departing from the spirit of the invention. Thus, it is intended that the present invention encompass modifications and variations of this invention provided those modifications and variations come within the scope of the appended claims and equivalents thereof.